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Use of Decoder Information for Detection of Start and End of Transmission in the ANDVT HF Modem

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CONTENTS

USE OF DECODER INFORMATION FOR DETECTION OF START AND END OF TRANSMISSION IN THE ANDVT HF MODEM

INTRODUCTION

This report addresses the use of information from an error correction decoder for maintenance of a signal presence indicator and the detection of end-of-transmission (EOT) in the hf modem of the Advanced Narrowband Digital Voice Terminal (ANDVT).

The ANDVT is being implemented as the CV-3591 tactical terminal [1]. It is characteristic of the new systems being used for hf communications. It incorporates error correction coding as an integral part of the modem. In a half-duplex implementation, ANDVT requires a reliable recognition of signal presence in order to synchronize its crypto function. This is accomplished by transmission of a modem preamble. Loss of signal presence is used as an indication of EOT. Prompt recognition of EOT is necessary in order to minimize the link turn-around time, which requires the modem to revert back to the preamble search mode.

In hf communications, the EOT function has normally been accomplished by either incorporating an EOT symbol at the end of every transmission or by reliance on signal-to-noise ratio (S/N) measurements.

The use of S/N measurements as an indicator of signal presence is unreliable under conditions often experienced in hf communications. Usually, an estimate of S/N is obtained by measuring the noise in a portion of the 3 KHz passband that contains little signal energy. For the ANDVT voice modem, this region is below 675 Hz and above 2812.5 Hz. Such S/N estimates can be corrupted by either extreme doppler shift, poor transmission filters, or interference.

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Thus, there is a need for a measurement technique (algorithm) which could be used to maintain signal presence under degraded conditions, yet would reliably detect a valid EOT. Also, such an algorithm could provide a basis for a method to detect the start-of-transmission (SOT), when a modem preamble is not used (point-to-point mode).

OBJECTIVES

The development of an algorithm for the maintenance of signal presence and the recognition of EOT has the following objectives:

(1) It is desirable, but not necessary, for the algorithm to be used for the acquisition of signal presence. Normally, in the net voice mode, signal presence is established by a robust modem preamble with an automatic hand-over to the data state. After which, the data signal is assumed to be present until declared absent.

(2) The algorithm should introduce minimum delay in the recognition of a valid EOT, in order to minimize the link turn-around time in net voice operations.

(3) The algorithm must tolerate some distortion of the passband by the transmission filters. The minimum passband requirements are to be established by acceptable bit error rate (BER) performance of the data signal, not by EOT requirements.

(4) The algorithm must withstand a substantial amount of inband interference and/or frequency selective fading, as characterized by hf channels.

(5) The algorithm must provide a low probability of incorrect dismissal to a valid signal.

A separate algorithm may be used to recognize SOT, when a modem preamble is not used. For this condition, the objectives are:

(1) The algorithm should introduce minimum delay in the recognition of a valid signal, in order to avoid loss of data, principally the voice processor identification (ID) frame. Yet, the algorithm must exhibit a very low probability of a false indication of signal presence.

(2) The algorithm must tolerate distortion of the passband, inband interference, and fading as described above.

ALGORITHM BASIS

The ANDVT signal design is composed of 39 tones with four-phase DPSK modulation at a frame rate of 44.444 frames/second. Twenty-four of the 39 tones are used to transmit information coded for error control, using the GOLAY (24,12) code. Two code words are transmitted each frame period. One code word is on the in-phase bits, and the other code word is on the quadrature-phase bits of the 24 tones. The 24 tones, which contain coded information, are permuted each frame period, to lessen the effects of filters and narrowband interference. A soft decision decoding algorithm [2] is used, where the error correction capability is increased from 3 to 7 errors per code word, by flagging the 4 bits with the highest probability of being in error (lowest confidence).

The EOT and SOT algorithms to be described rely on the use of the Golay soft decision decoder to obtain an estimate of signal presence. The algorithms are based on the probability that the decoder will find errors in N_4 of the four low confidence bits, when the total number of bits declared in error is N_t; where

$$0 \le N_t \le 7$$

and $0 \le N_4 \le 4$

and $N_4 \le N_t$

Table 1 shows the joint probability $p(N_t, N_4)$ that N_t bits were declared in error in a 24 bit code word and the N_4 of those bits were in the set of four bits with the lowest confidence. For example, p(5,3) is the probability that five errors were detected in the 24 bit word and that three of those were in the set of four bits with the lowest confidence. Data are presented in Table 1-a for an average decoded bit error rate (BER) of 6%, which represents a very poor but useable signal condition for digital voice. The data in Table 1-b are for a BER of 50% (no signal). These data are based on the decoding of 50,000 modem frames (100,000 code words) for Gaussian noise conditions, with no synchronization or frequency error. For a 6% decoded BER, the raw BER before decoding was approximately 8%.

Examination of the data in Table 1 indicates that there are six decoder conditions (set 1) that are reliable indicators of signal presence. They are the conditions where:

$$\frac{p(N_t,N_4) \text{ at BER of } 6\%}{p(N_t,N_4) \text{ at BER of } 50\%} \geq 2.0$$

These six conditions, their corresponding probability of occurrence, and ratios are shown in Table 2.

There are 13 other conditions (set 2) where the inverse of the above ratio is greater than 2.0 and thus favor the indication of a valid EOT. They are shown in Table 3. The remaining 11 combinations, which are shown in Table 4, do not favor either maintaining signal presence nor indicating EOT. The data in these tables illustrate that there are a very few strong indicators of signal presence. The indicators of EOT are more numerous than those for signal presence, but they are less reliable.

TABLE 1. Joint probability $p(N_t, N_4)$ that N_t bits were corrected in a code word and that N_4 of those bits were in the low four confidence values. Data given for two decoded BER.

N_4 \ N_t	0	1	2	3	4	5	6	7
0	.1352	.0444	.0232	.0109	.0004	.0000	.0000	.0000
1		.1980	.0860	.0688	.0272	.0008	.0000	.0000
2			.1144	.0704	.0694	.0278	.0009	.0000
3				.0328	.0257	.0354	.0120	.0003
4					.0036	.0056	.0051	.0020

TABLE 1-a. Joint probability $p(N_t, N_4)$ for BER of 6%

N_4 \ N_t	0	1	2	3	4	5	6	7
0	.0016	.0134	.0414	.0292	.0000	.0000	.0000	.0000
1		.0053	.0547	.1428	.0812	.0048	.0000	.0000
2			.0064	.0760	.1818	.1015	.0068	.0000
3				.0047	.0462	.1029	.0513	.0034
4					.0011	.0105	.0206	.0104

TABLE 1-b. Joint probability $p(N_t, N_4)$ for BER of 50%

TABLE 2. Summary of decoder conditions (Set 1) that could be used to maintain signal presence

N_t	N_4	$P_6 = p(N_t, N_4)$ at BER of 6%	$P_{50} = p(N_t, N_4)$ at BER of 50%	$\frac{P_6}{P_{50}}$
0	0	.1352	.0016	84.5
1	0	.0444	.0134	3.31
1	1	.1980	.0053	37.36
2	2	.1144	.0064	17.88
3	3	.0328	.0047	6.98
4	4	.0036	.0011	3.27
SUM		.5284	.0325	16.26

TABLE 3. Summary of decoder conditions (Set 2) that could be used to recognize EOT

N_t	N_4	$P_6 = p(N_t, N_4)$ at BER of 6%	$P_{50} = p(N_t, N_4)$ at BER of 50%	$\frac{P_{50}}{P_6}$
3	0	.0108	.0292	2.70
3	1	.0688	.1428	2.08
4	0	.0004	.0020	5.00
4	1	.0272	.0812	2.98
4	2	.0694	.1818	2.62
5	1	.0008	.0048	6.00
5	2	.0278	.1015	3.65
5	3	.0354	.1029	2.91
6	2	.0009	.0068	7.56
6	3	.0120	.0513	4.28
6	4	.0051	.0206	4.04
7	3	.0003	.0034	11.33
7	4	.0020	.0104	5.2
SUM		.2609	.7387	2.83

TABLE 4. Summary of decoder conditions (Set 3) that neither favor maintenance of signal Presence nor recognition of EOT

N_t	N_4	$P_6=p(N_t,N_4)$ at BER of 6%	$P_{50}=p(N_t,N_4)$ at BER of 50%	$\frac{P_6}{P_{50}}$
2	0	.0232	.0414	.56
2	1	.0860	.0547	1.57
3	2	.0704	.0760	.93
4	3	.0257	.0462	.56
5	0	.0000	.0000	
5	4	.0056	.0105	.53
6	0	.0000	.0000	
6	1	.0000	.0000	
7	0	.0000	.0000	
7	1	.0000	.0000	
7	2	.0000	.0000	
SUM		.2109	.2288	.92

Figure 1 shows the probability of maintaining signal presence vs. decoded BER, using either set 1 or set 2 or a simpler criteria based on the total number of errors corrected. The probability of maintaining signal presence using set 1 is equal to the total probability that the decoder output will be in one of the 6 conditions represented in set 1. The probability of maintaining signal presence using set 2 is equal to one minus the total probability that the decoder output will be in one of the 13 conditions of set 2.

From Figure 1, it may be seen that the use of the six decoder conditions of set 1 provide a relatively sharp discrimination between a poor but useable signal condition and an unuseable signal condition.

In the ANDVT, two Golay code words are transmitted each modem frame period. The data presented in Tables 1 to 4 and in Figure 1 do not consider the interrelationship that exists in the error patterns in both code words. A measure of this relationship is shown in Figure 2.

Figure 2 shows, as a function of BER, the probability that the signal will be detected either 0, 1, or 2 times/frame, when using the set 1 decoder conditions as the test criteria. These data are shown as a function of the average decoded BER. The probability of detecting signal presence only once per frame is a maximum at a BER of approximately 6%. The algorithms to be described for detection of EOT and SOT are based on these statistics.

ALGORITHM DESCRIPTION

Recognition of EOT

The following is a description of an algorithm that has been developed which uses the Golay soft decision decoder to recognize a valid EOT. The algorithm uses the restricted set of six decoder conditions, previously described in Table 2.

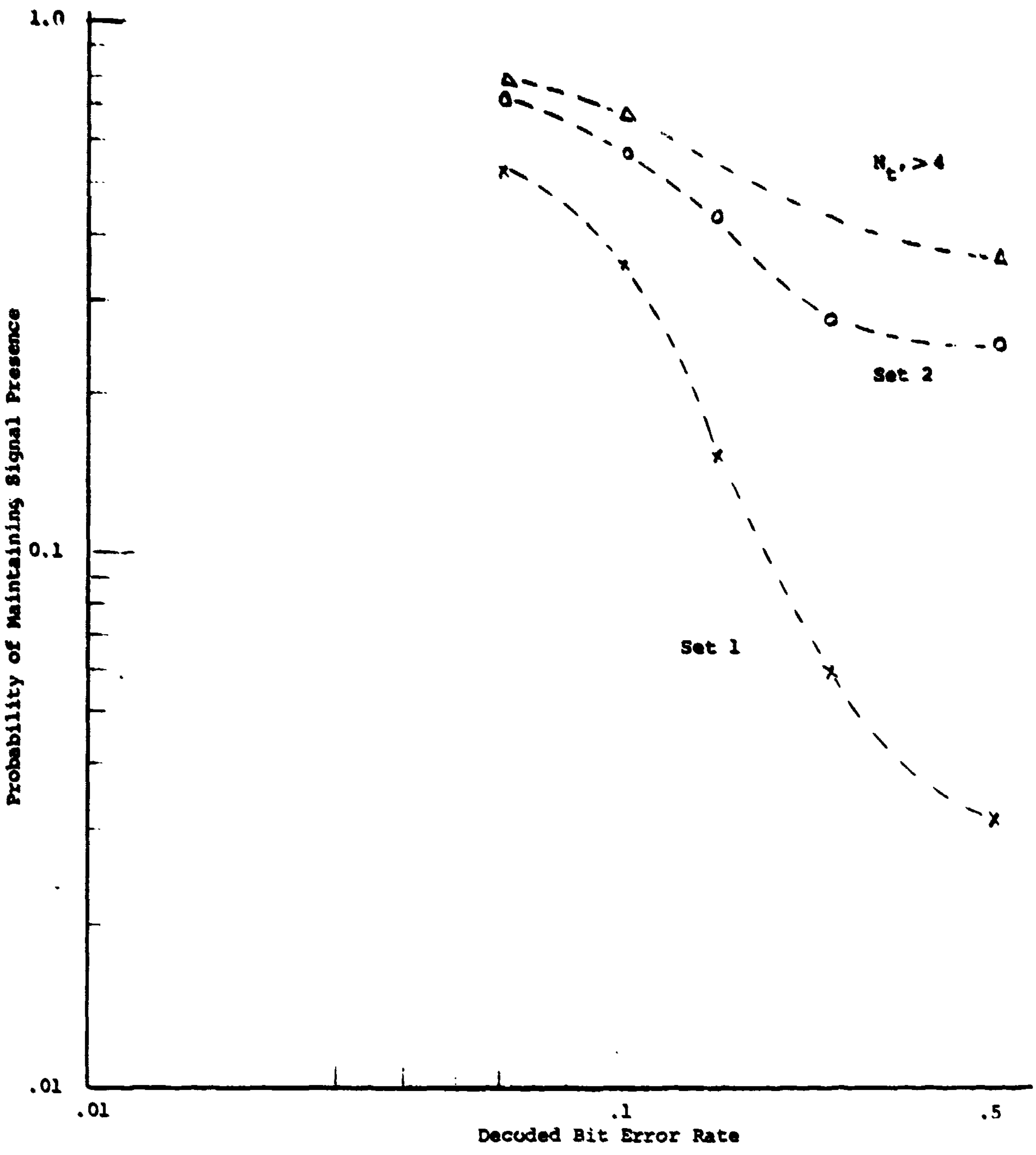

Fig. 1 — Probability of maintaining signal presence as a function of decoded bit error rate, based on different test criteria

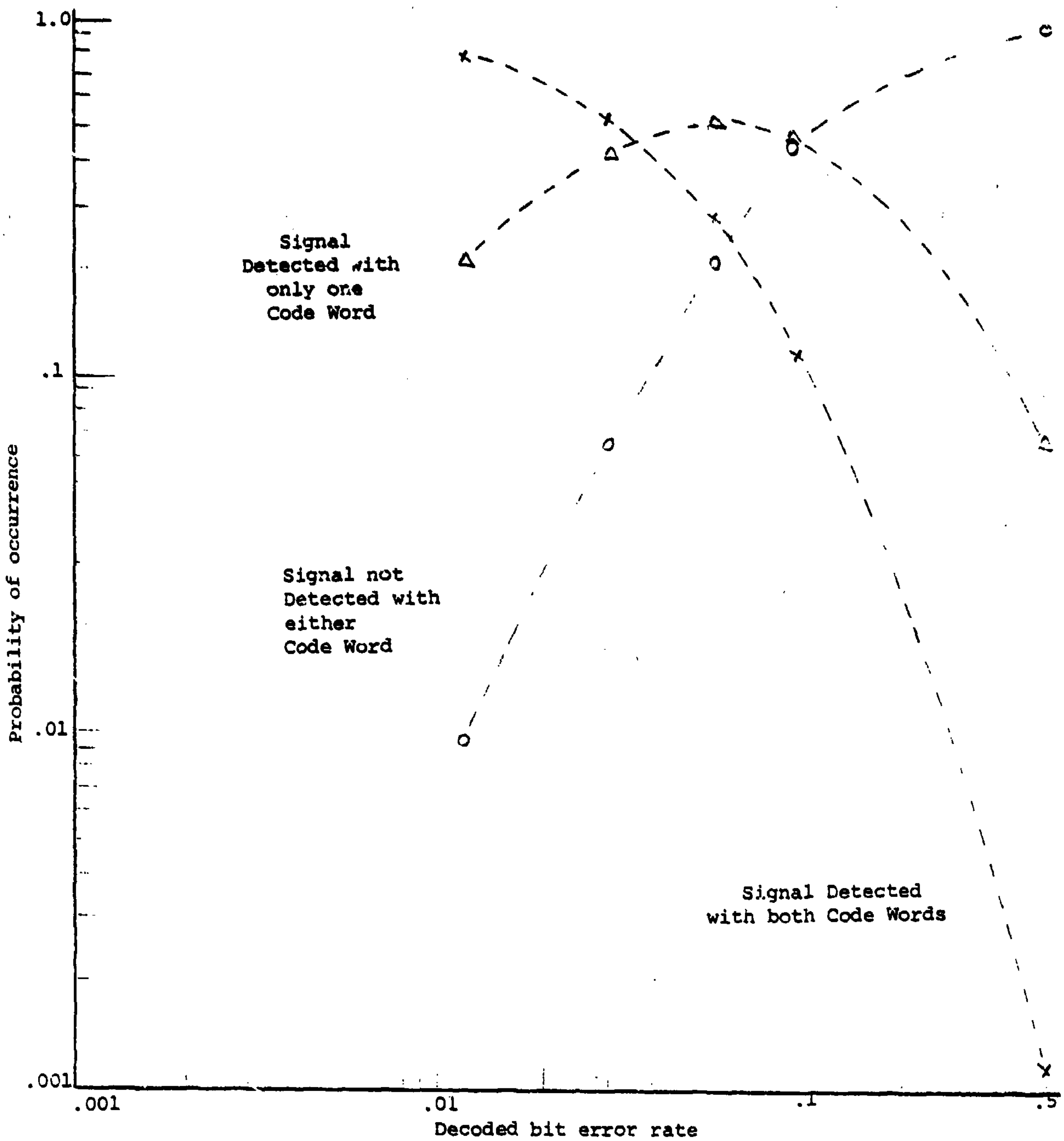

Fig. 2 — Probability that signal presence will be detected either zero, one, or two times per frame

In order to establish the parameters in the algorithm it was necessary to devise a performance criteria expressed in terms of the probability of maintaining signal presence as a function of the channel conditions, and the probability of recognizing a valid EOT. To determine what the design goals should be, it was assumed that for net operations the duration of most digital voice messages is less than 60 seconds. Thus, to have a 99.9% probability of maintaining signal presence for the full message period, at some average BER, there must be no more than 0.1% probability that the period between false indications of EOT (incorrect dismissals) is less than 2667 frame periods (60 seconds is approximately 2667 frames at 44.44 frames/second).

The desired objective for recognition of a valid EOT was established as a 95% probability of detecting EOT in 5 to 10 frames (0.1125 to 0.225 seconds), and/or a 99% probability of detecting EOT in 10 to 20 frames (0.225 to 0.45 seconds), under all conditions where useable communications can be maintained. These values were chosen after considering the impact of the length of the period to recognize EOT upon the total time involved in turning around a half-duplex link.

These two design goals conflict with each other. An algorithm that provides a very fast recognition of a valid EOT, usually has a high false dismissal rate under poor S/N conditions. The solution proposed is a compromise. The aim being to develop an adaptable algorithm that permits a rapid recognition of a valid EOT after a transmission with good signal conditions; but, when operating with a marginal signal condition, a longer period is allowed in which to recognize a valid EOT. That is, a fixed threshold, for all signal conditions, is not used.

The following rules have been developed for an adaptable algorithm for the maintenance of signal presence and the recognition of a valid EOT:

(1) Each frame period either increment or decrement a "loss of signal" (LS) counter, depending on the results of each code word.

(2) Increment the LS counter by the value INCR when the decoder declares that signal is not present, using for the test criteria the six decoder conditions described as set 1.

(3) Decrement the LS counter by the value (MIN+1-INCR) when the decoder declares that signal is present.

(4) After decoding both code words, EOT is declared if the LS counter reaches a threshold of ITHR. If the counter is less than zero, set it equal to zero.

The adaptive feature of the algorithm consists of changing the value of INCR depending on the past decisions of the decoder.

(5) If both code words indicate signal presence, the value of INCR is incremented by one, to a maximum of MIN. Increasing the value of INCR results in biasing the algorithm toward the rapid recognition of a valid EOT.

(6) The value of INCR is decremented by a value equal to the number of code words that indicated no signal present (0, 1, or 2), to a minimum of one. Decrementing the value of INCR results in biasing the algorithm toward maintaining signal presence.

Using the above rules, the value of INCR can vary from one to MIN. MIN is given a value equal to the minimum number of frames to recognize a valid EOT following a strong signal. Under that condition, it is assumed that the LS counter would be starting from an initial value of zero, and would be incremented at the fastest rate. The value of the LS counter after MIN frames would then represent the threshold ITHR to use for recognition of EOT. Table 5 contains examples of how the LS counter would accumulate, and how INCR would adapt for values of MIN from 4 to 6. The choice of the value MIN determines the overall performance of the algorithm.

TABLE 5. Examples of the adaptive features of the algorithm

FRAMES AFTER EOT	MIN	INCR	LS COUNTER
0	4	4	0
1		2	8
2		1	12
3		1	14
4		1	16 = ITHR
0	5	5	0
1		3	10
2		1	16
3		1	18
4		1	20
5		1	22 - ITHR
0	6	6	0
1		4	12
2		2	20
3		1	24
4		1	26
5		1	28
6		1	30 = ITHR

Recognition of SOT

ANDVT has a second voice mode which is referred to as the half-duplex point-to-point (p-p) mode. It is intended for two-party operation, rather than net operation. In the p-p mode the modem and cryptographic synchronization are established on the first transmission after going off-hook, and thereafter they "flywheel" through silence periods. Thus, for the p-p mode there is a need for a signal presence algorithm to detect the beginning of each message (SOT) after the initial transmission.

In order to establish a meaningful performance requirement for an SOT algorithm, it is necessary to examine the processing delay through the CV-3591. In the net voice mode, the one way delay through the system is approximately 1.84 seconds, plus the period required to recognize EOT. The turn-around delay time apparent to the user is twice this value plus the period to recognize EOT or approximately 3.68 + EOT seconds. Selecting six frame periods as a minimum value for EOT, for good S/N conditions, results in a total turn-around time for net operations of:

$$\begin{aligned} d_{net} &= 3.68 + 6(0.0225) \\ &= 3.815 \text{ seconds} \end{aligned}$$

Thus, this minimum EOT period represents approximately 3.5% of the total turn-around time in the net mode.

In the p-p mode, without the 1.52 seconds preamble transmission, the one way delay through the system is approximately 0.32 seconds plus the period to recognize EOT and the period to recognize SOT. Again, allowing six frames for EOT under good S/N conditions, the turn-around time apparent to the user in the p-p mode is:

$$d_{p-p} = 0.64 + 0.135 + SOT$$
$$= 0.775 + SOT$$

Thus, as SOT approaches zero, the minimum value of d_{p-p} approaches 20% of d_{net}. This ratio is approximately 24% for SOT of 6 frames. Permitting SOT to be much larger than 6 frames would reduce the apparent advantage to the user of having a p-p mode, in addition to the normal net mode.

It is justifiable to establish performance requirements for SOT using high S/N conditions, because if the decoded BER exceeds 3%, the probability of correctly detecting the ID frame decreases significantly. If the ID frame is not correctly detected by the terminal the voice synthesizer must verify proper synchronization using the 54 bit data frame, and this results in an increase in delay of a minimum of 16 frames (0.36 seconds).

Therefore, the desired objective for recognition of SOT was selected as a 99% probability of detection in six to ten frames at a 3% decoded BER.

The CV-3591 is required to operate over a large range of environmental conditions without any adjustments of the internal clock signals, for the lifetime of the equipment. Thus, for worse case conditions when operating in the p-p mode, it is necessary to receive a valid signal at least once every two minutes, after the initial transmission, in order to maintain the "flywheel" synchronization.

Therefore, a design goal of a 0.1% probability of a false alarm on the detection of a SOT in 5000 frames would provide adequate protection against disruption of an established p-p link (5000 frames at 44.44 frames/sec = 112.5 sec).

These objectives can be achieved by using the same algorithm that was used for detection of EOT and establishing a second threshold (ITHR2) lower than ITHR, which would be used for indication of SOT. For example, with a MIN of 5, ITHR

would be 22. During the silence periods between receptions in the p-p mode the LS counter would be at or near the threshold value of 22 and INCR should be one. Upon receipt of a p-p signal, the value of the LS counter would be decremented toward zero, and INCR would be incremented toward the value of MIN. Selection of a value for ITHR2 between ITHR and zero would establish the performance of the algorithm for SOT detection. The lower that value is, the longer period required to detect SOT, but the lower the probability of a false alarm.

BENCHMARK ALGORITHM

A benchmark algorithm was tested for comparison with the performance of the proposed EOT algorithm. It is based on the S/N measurements made each frame period. The S/N power ratio is equal to:

$$S/N = \frac{S+N}{N} - 1$$

where (S+N) is the average signal plus noise energy in the 39 frequency assignments, and N is the average noise energy in six "empty" frequency slots. Each frame period the LS counter is incremented by one if the S/N is less than a specified threshold (THR); otherwise, LS is set to zero. Thus, this algorithm is biased strongly toward maintaining signal presence; because, in order to declare EOT, it requires identification of MIN successive frames without signal presence.

The choice of MIN and the value of the S/N threshold (THR) determines the performance of the benchmark algorithm for Gaussian noise conditions. Also, performance is affected by the number of frequency slots used for the noise measurement. Fluctuations in the noise measurements are the principle cause of the variations in the measured S/N ratio. Noise energy is measured in only six slots

compared to 39 slots for the signal plus noise. Figure 3 shows the cumulative distribution function of the average noise energy/frame, as measured in either 6 or 39 slots. At the 99% point, the average noise energy on the 39 slots is 1.3 or less, and it is 2.1 or less when averaged over only 6 slots. This is a ratio of 2.1 dB. At the 99.9% point, the corresponding values are 1.45 and 2.65, for a ratio of 2.6 dB.

These data were obtained for the case that each of the in-phase and quadrature components were random variables, with a Gaussian amplitude distribution and zero mean. The noise power has a mean value of one and a variance of one.

PERFORMANCE

Detection of EOT

Figure 4 is a cumulative distribution function of the number of frames required to recognize a valid EOT. Three sets of data are shown for the condition that MIN is 5. The data shows the performance of the benchmark algorithm for a S/N threshold of 2.6 dB, and the performance of the adaptive algorithm for both good and poor communication conditions. The definition of a good channel being where INCR is equal to MIN at the end of the message. A poor channel results in INCR equal to one, at the end of the message.

An average energy per tone to noise density ratio of 2.6 dB is equivalent to a total signal-to-noise power density ratio of 36 dB, for the 39 tone ANDVT signal, using a 128 point FFT, and a sampling rate of 7200 Hz.

$$
\begin{aligned}
P/N_0 &= E_t/N_0 + 10 \log ((39)\ (7200)/128) \\
&= E_t/N_0 + 33.4 \text{ dB} \\
&= 2.6 + 33.4 \\
&= 36.0 \text{ dB}
\end{aligned}
$$

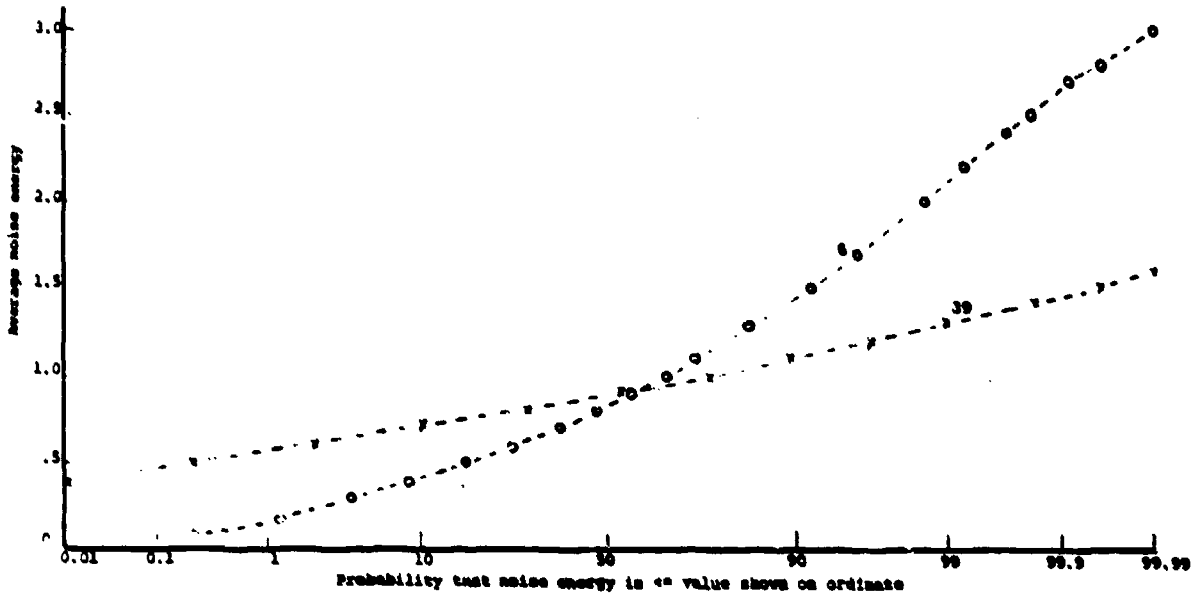

Fig. 3 — Cumulative distribution function of noise energy averaged over either 6 or 39 estimates

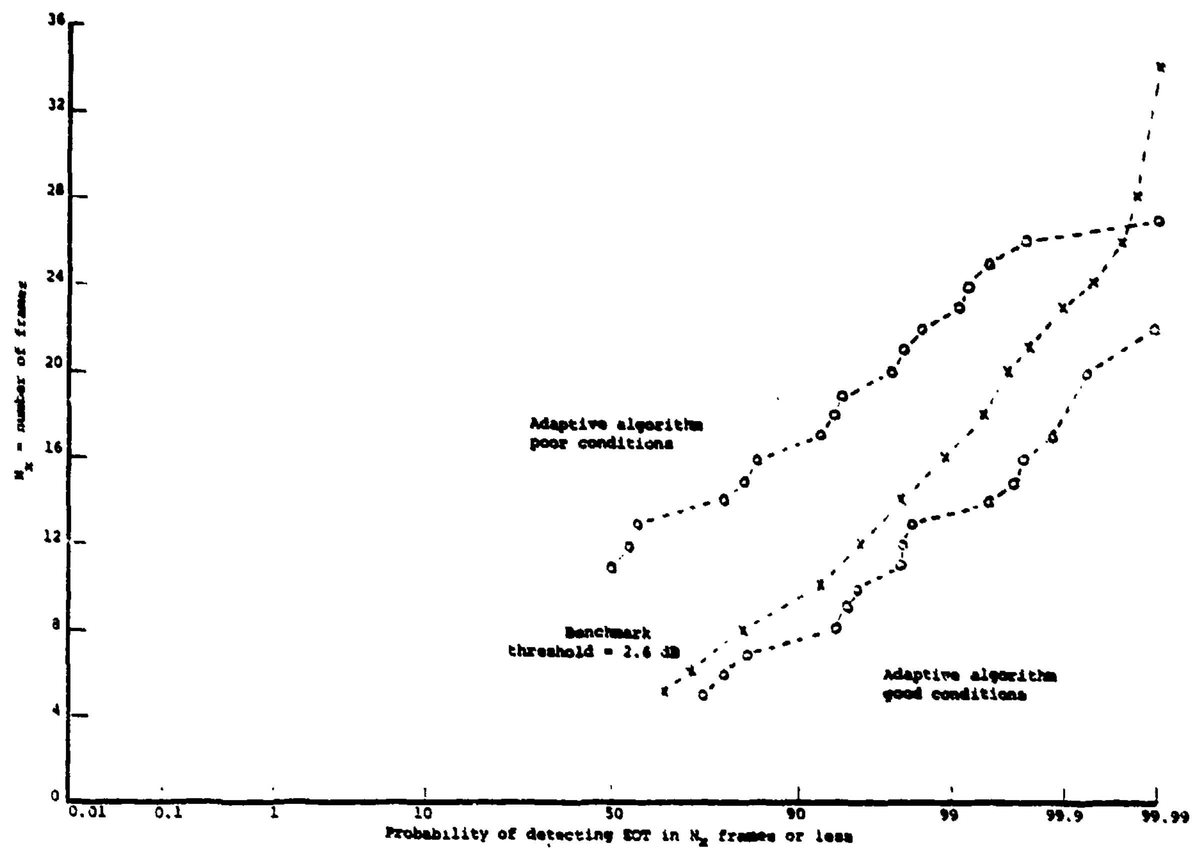

Fig. 4 — Comparison of performance of benchmark algorithm and proposed EOT algorithm for MIN of 5, for both good and poor signal conditions

For these conditions, with the benchmark algorithm, there is a 95% probability that a valid EOT will be detected within 12 frames, and a 99% probability that it will be detected within 17 frames.

Under good communication conditions, the adaptive algorithm, at a MIN of 5, will detect a valid EOT more rapidly than the benchmark technique. But, the opposite is true under poor conditions. For good conditions, there is a 95% probability that a valid EOT will be detected in 10 frames, and a 99% probability of detection in 14 frames. The corresponding values for poor conditions are 19 frames and 23 frames. Figure 5 shows the probability of detecting a valid EOT within N_X frames, under good signal conditions, for different values of MIN. Figure 6 shows similar data for poor conditions, and Table 6 is a comparison of these data.

Incorrect Dismissal of Signal Presence

The probability of a false indication of EOT in 2667 frames (60 seconds) is very much less than 0.1% for both algorithms, for MIN of 5 or more, with additive Gaussian noise producing a decoded BER of 6%. In a test duration of 50,000 frames (18.75 minutes), no false dismissals occurred for a MIN of 5, with the benchmark algorithm, and only one false dismissal occurred with the adaptive algorithm.

As the channel conditions degrade, so that the BER exceeds 6%, the probability of a false dismissal increases rapidly when using the adaptive algorithm. At a 10% BER, 17 false dismissals occurred in a test duration of 50,000 frames, using a MIN of 5. Increasing the value of MIN improves performance at this higher BER. Using a MIN of 6, no false dismissals occurred in 50,000 frames, at a decoded BER of 10%.

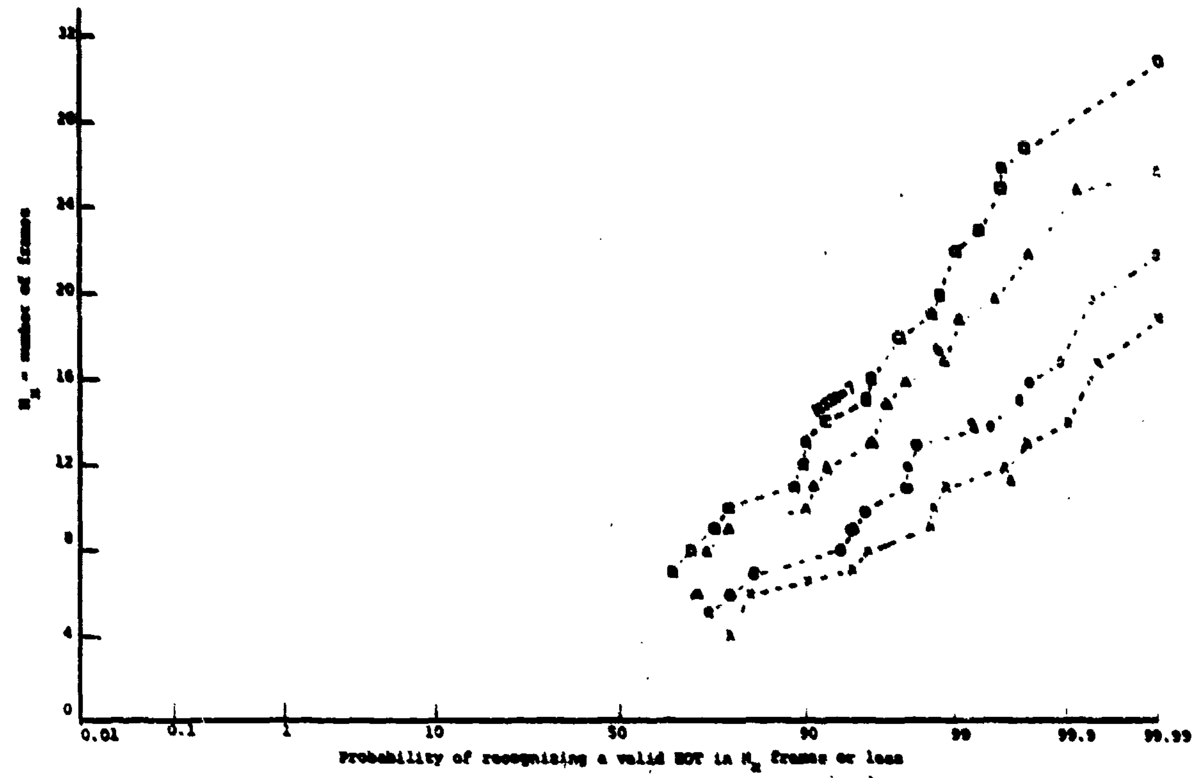

Fig. 5 — Cumulative distribution function of the number of frames required to detect a valid EOT for good conditions, with the adaptive algorithm

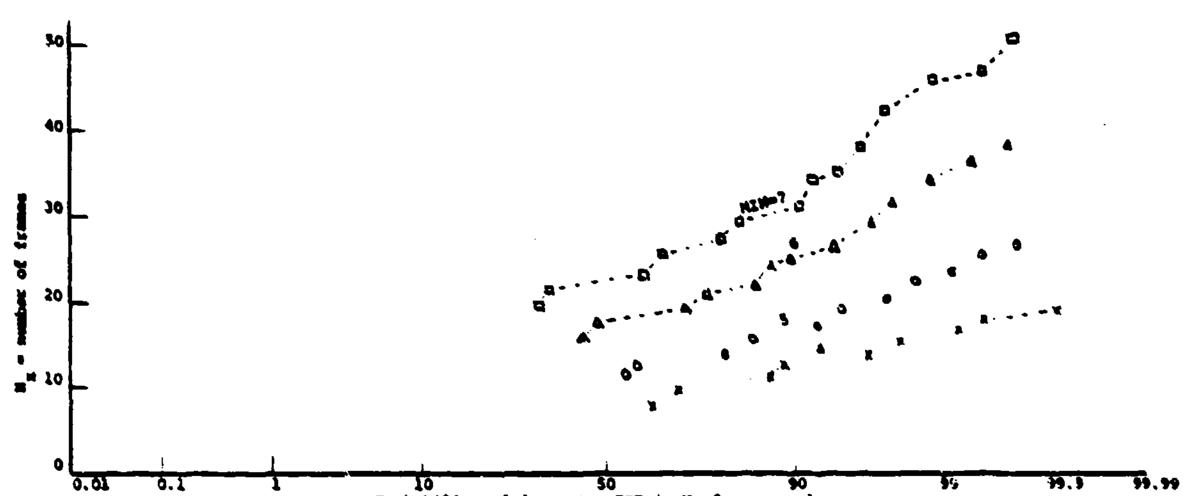

Fig. 6 — Cumulative distribution function of the number of frames required to detect a valid EOT for poor conditions, with the adaptive algorithm

TABLE 6. Summary of probability of detecting a valid EOT

MIN	FRAMES REQUIRED TO DETECT VALID EOT					
	ADAPTIVE, GOOD CONDITIONS		ADAPTIVE, POOR CONDITIONS		BENCHMARK	
	95%	99%	95%	99%	95%	99%
4	8	11	13	16		
5	10	14	19	23	12	17
6	13	19	28	35		
7	15	22	36	46		

Effects of CW Interference on Detection of EOT

Tests were performed with a CW tone interference in one slot with its amplitude equal to the desired tone, but with random phase. This condition produces a 50% raw BER on that tone. One interference tone is sufficient to seriously degrade the ability to detect a valid EOT, using the benchmark algorithm, for all conditions where the average interference/noise is greater than the threshold of 2.6 dB. Under that condition, the benchmark algorithm cannot distinguish between interference and signal.

Figure 7 is a cumulative distribution function of the number of frames required to detect a valid EOT with interference present, for a MIN of 5, using the benchmark algorithm where S/N is the criteria for signal presence. Data are presented for both good and poor signal conditions. The poor condition is for an average decoded BER of 6%, before interference is added. The good condition represents a 10 dB increase in signal level, which results in essentially an error-free reception, before the interference is added. These data indicate that at a BER of 6%, this interference condition did not affect the ability to detect EOT: but, when the signal level improved, the probability of detecting EOT decreased, rather than increased. With any further increase in signal level, it rapidly became impossible to detect EOT. Similar results would be obtained for a variety of interference conditions. But, these specific results are true only for the condition that the interference level increases in direct proportion to the improvement in S/N (i.e., the CW interference tone is always of the same amplitude as one of the desired data tones before the end of message).

Identical tests with CW interference were conducted using the adaptive algorithm, with a min of 5. The results are shown in Figure 8. For poor conditions,

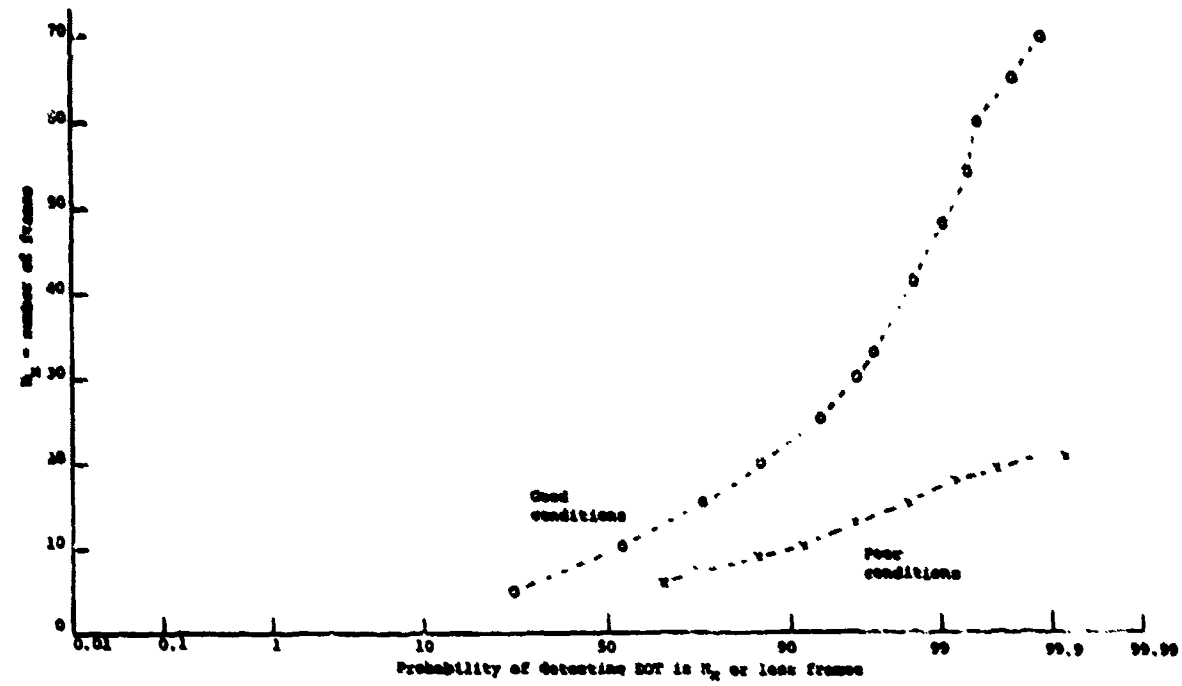

Fig. 7 — Cumulative distribution function of the number of frames to detect EOT, with interference present on one tone, using the benchmark algorithm, for a MIN of 5

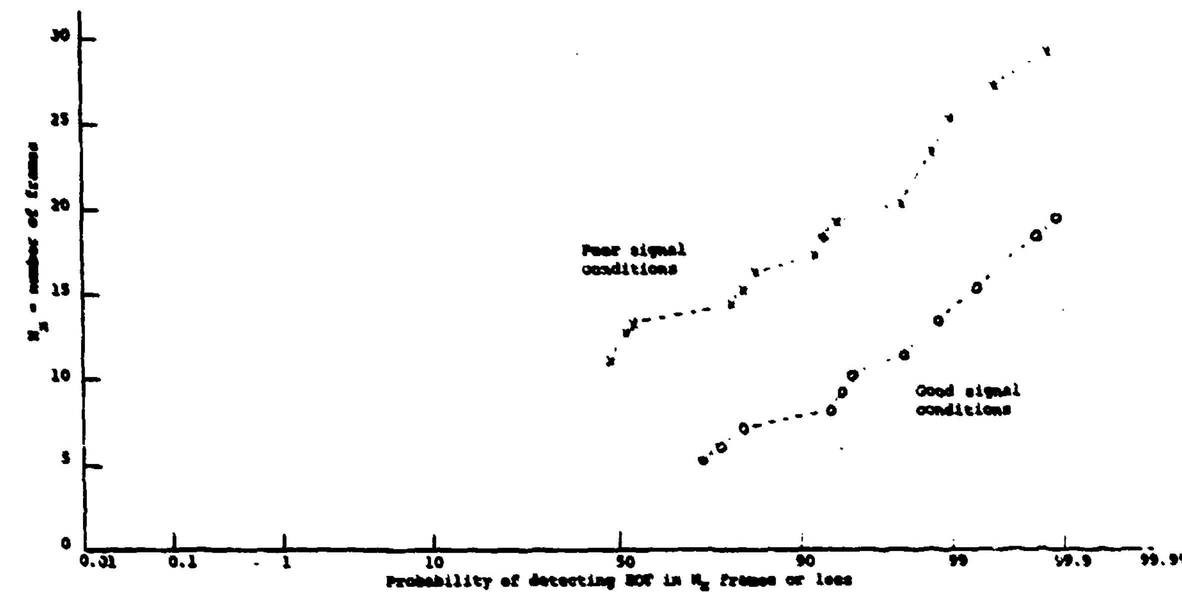

Fig. 8 — Cumulative distribution function of the number of frames required to detect EOT for the adaptive technique with CW interference present. for MIN of 5

the results with CW interference are almost identical to those shown in Figure 4 for Gaussian noise. Only a slight degradation occurred. Likewise, under good conditions, the performance with one CW tone was within one frame period of that achieved without interference at the 99% probability point.

Detection of SOT

Figure 9 is a cumulative distribution function of the number of frames required to recognize a valid SOT for MIN equal 5 with a threshold ITHR2 of 15, and for Gaussian noise conditions that result in a decoded BER of 3%, 6% and 10%. Figure 10 shows similar data for a MIN of 6 with ITHR2 equal to 20.

At a BER of 6%, SOT is correctly detected 99% of the time in 5 frames for a MIN of 5, and in 6 frames for a MIN of 6.

The test conditions insured that one frame of noise occurred between each test, so that the first frame of a valid signal must be used by the demodulator as the phase reference frame. The performance data shown in Figures 9 and 10 include the phase reference frame.

False Indication of Signal Presence

In a test duration of 50,000 frames with Gaussian noise input, no false alarms occurred for a MIN of 5 with threshold ITHR2 equal 15, nor for a MIN of 6 with a threshold of 20.

Expected Performance on a Fading Channel

The design of the EOT and SOT algorithms are based on statistics of the decoder performance for DPSK demodulation in Gaussian noise. The test results

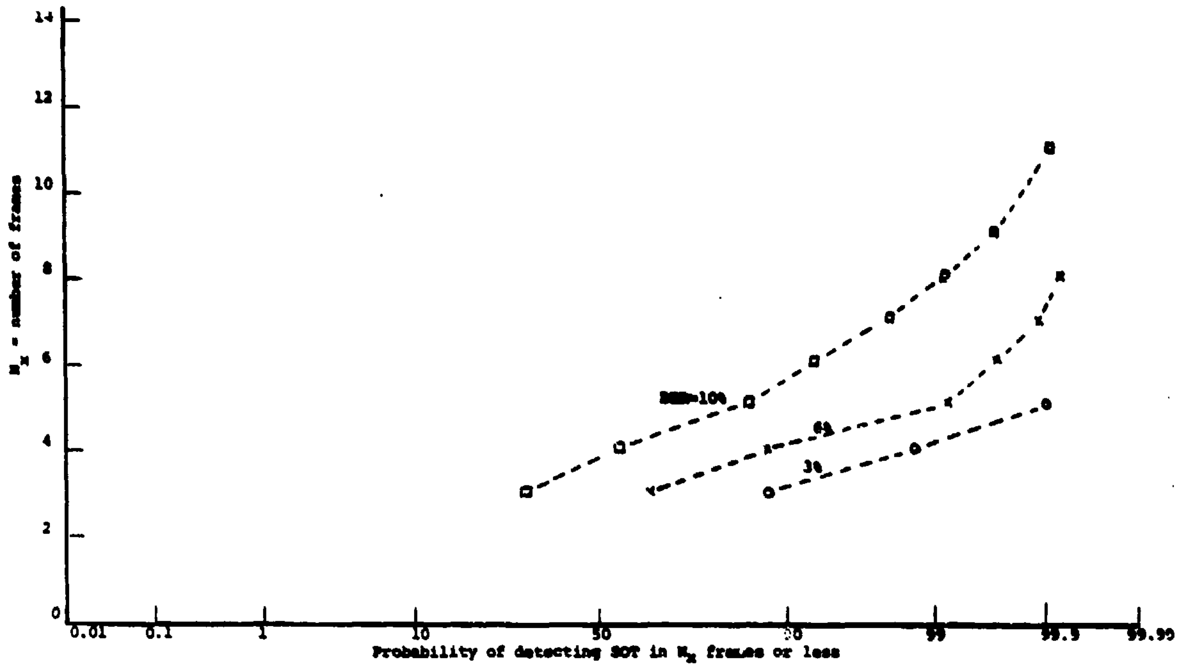

Fig. 9 — Cumulative distribution function of number of frames required to detect SOT, for MIN of 5, ITHR of 22, and ITHR2 of 15

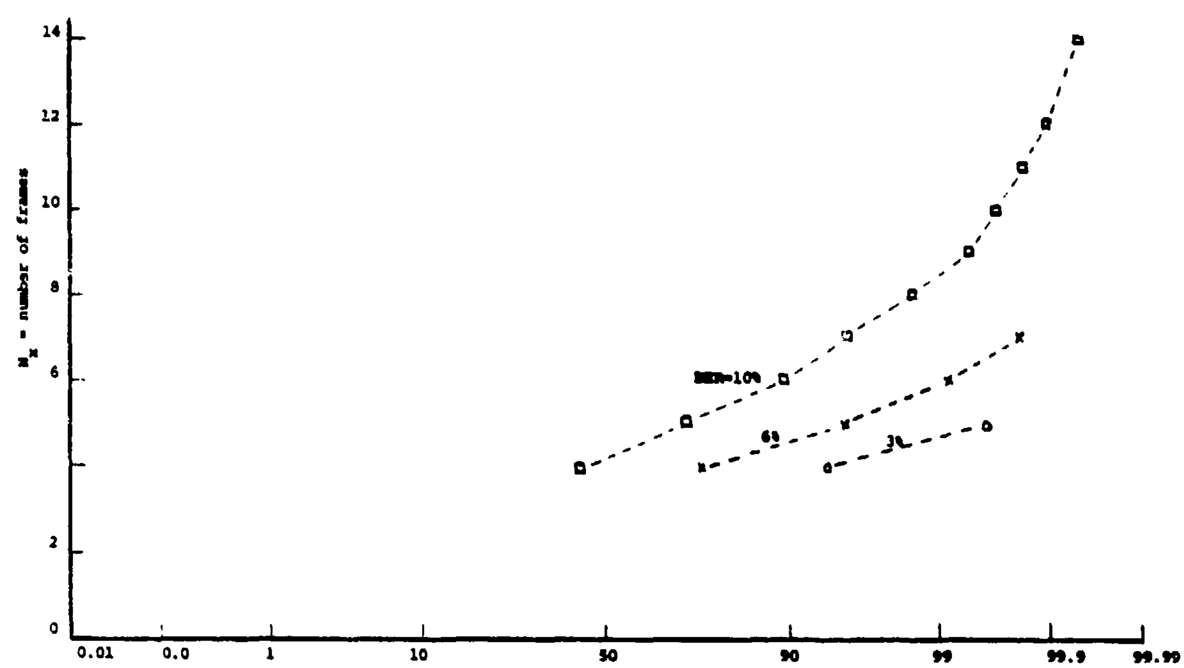

Fig. 10 — Cumulative distribution function of number of frames required to detect SOT, for MIN of 6, ITHR of 30, and ITHR2 of 20

are for the Gaussian channel, with and without CW interference. Tests have not been performed for a Rayleigh fading channel model but the algorithms are expected to perform well.

The two extreme conditions for Rayleigh fading are frequency-flat fading (simultaneous fading of all data tones) and independent fading on each data tone. Normal hf channels, with multipath propagations, are somewhere between these two conditions.

A slow frequency-flat fading channel with additive Gaussian noise can be viewed as a Gaussian channel with a slowly varying S/N. The modem frame rate is considered fast relative to the fade rate, thus the phase rotation imparted by the fading mechanism does not vary much in one frame period. So, performance of the DPSK demodulator will be controlled by the S/N ratio during a period of two frames.

The decoder errors will occur in bursts. The statistics of the number of errors detected in the four bits with the lowest confidence relative to the total number of errors detected should be the same as for a Gaussian channel with an average S/N equal to the instantaneous S/N measured at a particular point in the fading cycle (a period of two frames). Also, the interrelationship between errors in the two code words should be the same as for the Gaussian channel.

The second extreme example of a fading channel is when each of the 39 data tones is fading independently. This condition is approached when several strong paths are propagating and the differential delay between paths is very large, producing a very narrow correlation bandwidth.

For this extreme condition, all bits in the 24 bit code word have the same probability of error and that probability is constant from frame to frame. There is no other interrelationship between the errors in a code word. Whether a particular bit is in error is dependent only on the strength of the signal on a given tone. The relationship of the errors to the confidence measurements is still related to the S/N ratio for that tone, assuming a slow fade rate relative to the frame rate. Thus, there is still good correlation between the bit with low confidence and the bits detected in error. In fact, the correlation should be much better than for frequency-flat fading, because of the large variation in amplitudes of the 24 tones in a given frame (it is easier to discriminate between good and poor tones).

Thus, for these two extreme fading conditions, the algorithms are expected to work well. They will work better under highly frequency selective fading conditions than under frequency-flat fading conditions, which are more like poor Gaussian channels.

The types of channel conditions that would result in poor performance are the types for which DPSK demodulation performs poorly. Those are channels with wide band noise bursts, phase jitter independent of the additive noise, and fade rates that are not slow relative to the frame rate.

It is conjectured that the algorithms do not result in any new restriction on acceptable channel conditions, beyond those required for use of DPSK modulation.

CONCLUSIONS

1. An adaptive algorithm has been devised that uses information from the soft decision GOLAY decoder to indicate signal presence. Its capability to

maintain signal presence is comparable to using S/N measurements, under Gaussian noise conditions, where the average decoder BER does not exceed 6%. In a test of 50,000 frames (18.75 minutes) with additive Gaussian noise the adaptive algorithm, with a MIN of five, caused only one false dismissal of signal presence. None occurred with a non-adaptive benchmark algorithm based on S/N measurements.

2. For good channel conditions, the algorithm detects a valid EOT more rapidly than a bench mark algorithm based on S/N measurements. For poor conditions, the algorithm takes longer to recognize EOT, in order to minimize false dismissals.

3. In the presence of constant level CW interference the adaptive algorithm performance improves with an increase in S/N. That is, for a decrease in the level of the additive Gaussian noise. In contrast, when S/N measurements are used to detect EOT, performance does not improve with an increase in S/N.

4. The criteria used for signal presence by the adaptive algorithm are determined in the bandwidth of the data signal. This minimizes erroneous results and reduces unnecessary requirements for additional bandwidth and fidelity in the transmission equipment.

5. The same algorithm may be used to detect signal presence in the p-p mode, when a modem preamble is not transmitted, by establishing a second threshold relative to the one used for declaration of EOT.

6. The algorithms are expected to perform well under all hf channel conditions for which the DPSK signal design is applicable. The algorithms are as robust as the basic signal design for digital voice transmission.

7. The algorithms are expected to provide improved performance over the use of S/N measurements for the range of fading and interference conditions normally experienced on hf channels. Tests to date of the full scale engineering model of the CV-3591 over an ionospheric propagation path support these conclusions.

ACKNOWLEDGMENTS

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SYMBOL GLOSSARY

ANDVT	Advanced Narrowband Digital Voice Terminal
BER	bit error rate
CW	continuous wave
dB	decibels
d_{net}	turn around delay time through CV-3591 in net mode
d_{p-p}	turn around delay time through CV-3591 in point-to-point mode
DPSK	differential phase shift keyed
E_t/N_o	energy per tone to noise density ratio in decibels
EOT	end of transmission
FFT	fast Fourier transform
hf	high frequency
Hz	Hertz
ID	identification frame
INCR	incrementation value in adaptive algorithm for the detection of EOT and SOT
ITHR	threshold value for loss of signal counter use in adaptive algorithm
ITHR2	threshold value for detection of SOT in p-p mode
kHz	kiloHertz
log	logarithm to base 10
LS	loss of signal counter
MIN	minimum number of frames required by algorithm to detect loss of signal
N_x	number of frames required to achieve a given probability of occurrence of an event
π	constant pi

P/N_0	total signal power to noise density ratio in decibels
$p(N_t, N_4)$	probability that decoder corrects N_t bits and that N_4 of those are in the set of 4 bits with the lowest confidence
S/N	signal to noise power ratio
(S+N)/N	signal plus noise to noise power ratio
SOT	start of transmission
THR	threshold value for loss of signal counter used in benchmark algorithm